

## SCANNING PROBE MICROSCOPE AND SOLENOID DRIVEN CANTILEVER ASSEMBLY

### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

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### BACKGROUND OF THE INVENTION

The present invention relates to scanning probe microscopy, and in particular to the construction of a combination scanning probe and optical microscope for use in atomic force microscopy.

High quality optical views of a sample under investigation by a scanning probe microscope may be obtained by combining the scanning probe microscope with an optical microscope. The optical view may be used, for example, to view gross features on the sample and track the position of the scanning probe with respect to the gross features. In this manner, the scanning probe may be conveniently maneuvered to particular areas of interest on the sample. The optical view may also be used to monitor processes optically as the scanning probe touches or manipulates molecules on the sample. A variety of combined scanning probe and optical microscope arrangements have been proposed. However, the presence of the optical microscope assembly tends to degrade the scanning probe performance because the optical microscope assemblies used tend to be relatively massive and, as such, tend to transfer significant low frequency resonant vibrational frequencies to the sample stage. As a result, the sample stage undergoes significant vibrational displacement, directly degrading the scanning probe analysis. Accordingly, there remains a need in the art for a combined scanning probe and optical microscope which is less prone to low frequency vibration than the designs of the prior art.

Another challenge associated with the design and operation of combined scanning probe and optical microscopes is presented in the context of magnetically induced oscillation of the scanning probe. Solenoids are commonly used in this art to induce oscillation in the scanning probe. Locating the solenoid for optimum probe displacement and control has traditionally been problematic. Accordingly, there exists a further need in the art for a scanning probe microscope design where a solenoid may be arranged in an optimum configuration.

Still another challenge associated with the design and operation of combined scanning probe and optical microscopes is presented in the context of sample placement, removal, and replacement. Typically, where an optical microscope is combined with a scanning probe microscope, the resulting design is cumbersome in that it is difficult to place, remove, and replace samples. Accordingly, there exists a further need in the art for a scanning probe microscope design that provides for convenient sample placement, removal, and replacement.

#### BRIEF SUMMARY OF THE INVENTION

These needs are met by the present invention wherein, in accordance with one embodiment of the present invention, a combined scanning probe and optical microscope is provided. The microscope comprises a sample stage, a scanning probe microscope, an optical microscope, a microscope coupling, and a sample stage support. The sample stage defines an upper surface and a lower surface. The scanning probe microscope is configured to examine a surface of a sample supported by the upper surface of the sample stage from above the sample stage. The optical microscope is configured to examine a sample supported by the upper surface of the sample stage from below the sample stage. The microscope coupling mechanically couples elements of the scanning probe microscope to elements of the optical microscope. The sample stage support is configured to isolate the sample stage from the optical microscope. The sample stage, the scanning probe microscope, and the sample stage support define relatively high frequency mechanical resonances. The optical microscope defines relatively low frequency mechanical resonances. The microscope coupling, the sample stage, and the sample stage

support are arranged to inhibit differential motion between the sample stage and the scanning probe microscope in the event of low frequency vibrations in the optical microscope.

The combined scanning probe and optical microscope is preferably designed such that a critical path coupling low frequency vibrations generated in the optical microscope to a sample supported by the sample stage runs from the optical microscope, through the microscope coupling, the sample stage support, and, finally, the sample stage. The sample stage support and the sample stage are preferably designed such that the critical path is not conducive to low frequency vibrational coupling. The scanning probe microscope, the optical microscope, and the microscope coupling may define a microscope chassis and the sample stage support may be configured to function as the sole significant source of vibro-mechanical coupling between the sample stage and the microscope chassis.

In accordance with another embodiment of the present invention, a scanning probe microscope is provided comprising a sample stage, a scanning probe microscope, a microscope coupling, a sample stage support, and a slide-mounted stage assembly supported by a microscope chassis. The scanning probe microscope is configured to examine a surface of the sample. The microscope coupling supports elements of the scanning probe microscope. The sample stage support is configured to suspend the sample stage from the microscope coupling. The slide-mounted stage assembly is arranged to permit slidable movement of the sample stage and the sample stage support relative to the microscope chassis.

In accordance with yet another embodiment of the present invention, a scanning probe microscope is provided comprising a sample stage, a scanning probe microscope configured to examine a surface of a sample supported by the sample stage, a microscope coupling, and a sample stage support configured to suspend the sample stage from the microscope coupling. The scanning probe microscope includes a solenoid driven cantilever assembly comprising a cantilever unit, a probe tip, and a solenoid unit. The cantilever unit is positioned above the sample stage and comprises a flexible cantilever having a free end and a confined end. The probe tip is defined at the free end of the flexible cantilever. A solenoid unit is positioned above

the cantilever unit and comprises a magnetic core and a solenoid winding. The solenoid unit is configured to cause movement of the free end of the flexible cantilever.

In accordance with yet another embodiment of the present invention, a solenoid driven cantilever assembly is provided comprising a cantilever unit, a probe tip, and a solenoid unit.

5 The cantilever unit comprises a flexible cantilever having a free end and a confined end. The probe tip is defined at the free end of the flexible cantilever and defines an apex on a lower side of the cantilever unit. A solenoid unit is positioned above the cantilever unit and comprises a magnetic core and a solenoid winding. The solenoid unit is configured to cause movement of the free end of the flexible cantilever.

10 Accordingly, it is an object of the present invention to provide a combined scanning probe and optical microscope which is less prone to low frequency vibration than the designs of the prior art, a scanning probe microscope design where a solenoid may be arranged in an optimum configuration, and a scanning probe microscope design that provides for convenient sample placement, removal, and replacement. Other objects of the present invention will be  
15 apparent in light of the description of the invention embodied herein.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The following detailed description of the preferred embodiments of the present invention can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

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Fig. 1 is an illustration of a combined scanning probe and optical microscope according to one embodiment of the present invention;

Fig. 2 is an illustration of the combined scanning probe and optical microscope of Fig. 1 showing the scanning probe portion of the microscope in a slide-out configuration;

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Fig. 3 is an illustration of a slide-out mechanism for use in the microscope of the present invention;

Fig. 4 is an illustration of a sample stage, scanning probe microscope, microscope coupling, and sample stage support according to the present invention; and

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Fig. 5 is an illustration of a solenoid driven cantilever assembly according to the present invention

## DETAILED DESCRIPTION

A combined scanning probe and optical microscope **10** according to the present invention is described herein with collective reference to Figs. 1-4. The microscope **10** generally includes a scanning probe microscope **20**, an optical microscope **30**, a microscope coupling **40**, a sample stage **50**, and a sample stage support **60**.

The sample stage **50** defines an upper surface **52** and a lower surface **54**. A sample (not shown) is placed upon the upper surface **52** for examination and may, optionally, be positioned within a fluid crucible **56** and submerged in a body of fluid to enhance examination by the scanning probe microscope **20**. The particular manner in which the scanning probe microscope **20** is employed to examine the sample is not the subject of the present invention and may be gleaned from related teachings present in any one of a number of U.S. Patents, including U.S. Patent Nos. 6,134,955, 6,133,955, 6,121,611, 5,983,712, 5,866,805, 5,805,448, 5,760,396, 5,753,814, 5,750,989, 5,675,154, 5,581,082, 5,495,109, the disclosures of which are incorporated herein by reference. For example, the position of the scanning probe microscope **20** may be adjusted by means of micrometer screws (not shown) which translate the scanning probe microscope **20** over the surface of the sample under examination.

For the purposes of defining and describing the present invention, with the exception of the embodiment of the present invention illustrated in Fig. 5, it will be sufficient to note that the scanning probe microscope **20** is supported by a microscope chassis **15** and includes a cantilever unit **22** positioned above the sample stage **50** and comprising a flexible cantilever **24** having a free end **26** and a confined end **28**. A probe tip **25** is defined at the free end **26** of the flexible cantilever **24** (see Fig. 5). Accordingly, as is illustrated in Figs. 1, 2, and 4, the scanning probe microscope **20** is configured to examine a sample supported by the upper surface **52** of the sample stage **50** from above the sample stage **50**. The optical microscope **30** includes an optical objective below the sample stage **50** focused through a transparent sample stage **50**, or through an aperture or window in the sample stage **50**, onto the region of the sample scanned by the scanning probe microscope **20**. As such, the optical microscope **30** may be used to examine the

sample from below the sample stage 50. As is illustrated in Figs. 2 and 4, the microscope coupling 40 mechanically couples elements of the scanning probe microscope 20 to elements of the optical microscope 30.

The optical microscope 30 is typically a massive object and, as such, is subject to relatively low frequency mechanical resonances. In contrast, the scanning probe microscope 20 is typically subject to relatively high frequency mechanical resonances. According to the arrangement of the present invention, the microscope coupling 40, the sample stage 50, and the sample stage support 60 are arranged such that the presence of the low frequency vibrations in the optical microscope 30 do not excite differential motion between the scanning probe microscope probe 20 and the sample stage 50 because of high frequency vibrations associated with the scanning probe microscope probe 20 and the sample stage 50. Further, the high frequency vibrations in the scanning probe microscope 20 do not create relative motion between the sample stage 50 and the scanning probe microscope 20.

Specifically, it is important to note that the sample stage 50 is not the microscope stage of the optical microscope 30 and, as such, is not part of the optical microscope 30. Rather, the sample stage support 60 supports or suspends the sample stage 50 at distal ends 62 of a plurality of suspension members 64 extending from the microscope coupling 40 and, as such, isolates the sample stage 50 from the optical microscope 30 and the microscope coupling 40. The critical path coupling any low frequency vibrations generated in the optical microscope to a sample under examination runs from the optical microscope 30, through the microscope coupling 40, the sample stage support 60, and the sample stage 50, to the sample. The scanning probe microscope 20, the optical microscope 30, and the microscope coupling 40 define a microscope chassis 15 and the sample stage support 60 is configured to function as the sole significant source of vibro-mechanical coupling between the sample stage 50 and the microscope chassis. For the purposes of defining and describing the present invention, it is noted that a significant source of vibro-mechanical coupling comprises any source of coupling that would lead to detectable performance degradation of the combined microscope.

The sample stage support **60** and the sample stage **50** are designed such that the critical path is not conducive to low frequency vibrational coupling. Specifically, in order to make the resonant frequency of the sample stage **50** significantly higher than that of the optical microscope **30**, the suspension members **64** extending from the microscope coupling **40** should be configured to define a minimum bending moment, i.e., they should be as short as practical and have a diameter that is as large as practical. For example, and not by way of limitation, the suspension members **64** are preferably no more than 1 cm in length and no less than 0.5 cm in diameter. It is contemplated that other dimensional combinations will also be suitable for practicing the present invention. For the purposes of defining and describing the present invention, it is noted that low frequency vibrations or mechanical resonances are in the range of about 0.1 Hz to about 100 Hz. High frequency vibrations or mechanical resonances are well above 100 Hz.

The sample stage **50** should be rigid and its mass should also be as small as practical to further ensure that its resonant frequency is significantly higher than that of the optical microscope **30**. According to one embodiment of the present invention, the sample stage **50** comprises a stainless steel disk of 5 cm diameter and 0.3 cm thickness. Again, it is contemplated that other materials and dimensional combinations will also be suitable for practicing the present invention.

To enable fine adjustment of the position of the sample stage **50**, each of the suspension members **64** may comprise a partially or fully threaded elongate rigid shaft or screw. Each shaft or screw **64** supports a portion of the sample stage **50** through the attractive force generated by a magnetic ball **65** secured to its distal end **62**. Each adjustable rigid shaft or screw **64** is engaged either in a threaded bore in the microscope coupling **40** or in a threaded bore formed in an additional member supported by the microscope coupling **40**.

Preferably, the microscope coupling **40** includes or is mounted to a slide-mounted movable stage assembly **70**. The movable stage assembly **70** is arranged to permit movement of the sample stage **50** and the sample stage support **60** relative to the optical microscope **30** and chassis **15**. As is illustrated in Fig. 2, the range of movement of the slide-mounted stage



assembly 70 is preferably sufficient to enable movement of the sample stage 50 away from the optical microscope 30 and chassis 15 to permit removal and replacement of the sample or the entire sample stage 50 independent of any interference by the optical microscope 30 or the chassis 15. Stated differently, where the optical microscope 30, the scanning probe microscope 20, and the microscope coupling 40 define a sample stage enclosure, the movable stage assembly 70 preferably defines a range of movement sufficient to enable movement of the sample stage 50 outside of the sample stage enclosure.

In the illustrated embodiment, referring to Figs. 2 and 4, it is noted that the microscope coupling 40 is mounted to the movable stage assembly 70 about a circumferential mounting zone 42 defined in the coupling 40. The movable stage assembly 70 may also form an integral part of the microscope coupling 40. It is contemplated that the movable stage assembly 70 of the present invention will have utility and advantages outside of the context of combined scanning probe and optical microscopes. For example, the movable stage assembly 70 may be useful in the context of any scanning probe microscope application where it would otherwise be difficult to replace a sample under analysis.

Referring now to Figs. 4 and 5, it is noted that the microscope 10 of the present invention may also be provided with a specialized solenoid driven cantilever assembly 80. Generally, the cantilever assembly 80 comprises a cantilever unit 22, a probe tip 25, and a solenoid unit 82 positioned above the cantilever unit 22. The solenoid unit 82 comprises a magnetic core 84 and a solenoid winding 86 and is configured to cause movement of the free end 26 of the flexible cantilever 24. Applicants note that, for the purposes of defining and describing the present invention, the manner in which the solenoid unit is employed to impart movement to the flexible cantilever 24 is not the subject of the present invention and may be gleaned from related teachings present in any one of a number of U.S. Patents, including those identified above.

The solenoid unit 82 of the present invention is particularly advantageous because it is positioned above the cantilever unit 22, outside of the optical path 90 defined between a laser source 92 and detector 94 used to monitor cantilever movement. Further, the cantilever unit 22

may be positioned directly adjacent to, mechanically coupled to, or secured proximately or directly to the magnetic core **84** of the solenoid unit **82**, optimizing the effect of the magnetic field generated by the solenoid unit **82** on the flexible cantilever **24**.

As is illustrated in Fig. 5, the magnetic core **84** defines an extended portion **88** outside of the solenoid winding **82** and the cantilever unit **22** is mechanically coupled or secured to the extended portion **88** of the magnetic core **84**. The cantilever unit **22** may further comprise a cantilever support chip **23** to which the confined end **28** of the flexible cantilever **24** is secured. The cantilever support chip **23** may, in turn, be secured to the magnetic core **84** of the solenoid unit **82**. Preferably, the cantilever unit **22** is releasably secured to the magnetic core **84** by means of a spring-loaded strap **85** and a releasable clip **87**. It is contemplated that a variety of arrangements may be provided to position the cantilever unit **22** proximate to the magnetic core.

Referring further to Fig. 5, the solenoid driven cantilever assembly **80** may further comprise an optically transparent element **81** arranged to pass light to an upper side of the cantilever unit **22** proximate to the free end of the flexible cantilever **24**. As is illustrated in Fig. 5, the solenoid winding **86** is wound about portions of the magnetic core **84** and the optically transparent element **81**, which may be a glass block, a hollow tube, a lens element, etc.

Having described the invention in detail and by reference to preferred embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims. More specifically, although some aspects of the present invention are identified herein as preferred or particularly advantageous, it is contemplated that the present invention is not necessarily limited to these preferred aspects of the invention.

What is claimed is: